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AN OBSERVATION PLANNING TOOL FOR THE MEERKAT RADIO TELESCOPE

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Abstract

The South African Radio Astronomy Observatory (SARAO) allocates time on the MeerKAT Radio Telescope to the scientific community to maximize its impact on radio astronomy while fostering South African scientific leadership and human capital development. To streamline and optimize this process, SARAO has developed an Observation Planning Tool (OPT), which allows astronomers to define and plan observations on the telescope. The submitted observations are then processed by an Astronomer on Duty (AOD), before being scheduled.

In this paper, we detail how the OPT supports SARAO's broader mission of effectively operating its radio telescope to produce usable scientific data by enhancing the efficiency, transparency, and scientific utility of the scheduling process. We describe the tool's functionality, design rationale, and ongoing improvements. Key features include a calibrators catalogue; the ability to simulate or dry-run observations; a scheduling assistant to aid the scheduler's optimizations efforts and future schedule plan of observations.

INTRODUCTION

The MeerKAT Radio Telescope is a project of the South African Radio Astronomy Observatory (SARAO), operating under the National Research Foundation (NRF). Officially inaugurated in 2017, MeerKAT consists of 64 interlinked receptors located in the Karoo region of the Northern Cape, South Africa. Originally conceived as the Karoo Array Telescope (KAT) with only 7 receptors, the project was expanded when the South African government increased funding. This expansion led to the new name "MeerKAT" meaning "more of KAT".

MeerKAT was developed as a precursor to the intergovernmental Square Kilometre Array (SKA), a next-generation facility that will combine thousands of receptors and associated infrastructure across South Africa and Australia. Once complete, the SKA will be the largest and most powerful radio telescope in the Southern Hemisphere, with an effective collecting area of one million square meters.

Since its commissioning, MeerKAT has delivered groundbreaking science and continues to operate at the forefront of radio astronomy. Its achievements include producing the most detailed image yet of the Galactic Centre region. Ultimately, MeerKAT will be integrated into the SKA, extending its legacy as a critical stepping stone toward one of the most ambitious scientific instruments ever built.

Like other astronomy observatories, SARAO makes its telescopes available to interested parties, typically professionals in the field of radio astronomy, through Open Time Calls (OTCs). An OTC is the process SARAO uses to invite and collect radio observation proposals from astronomers worldwide. These proposals undergo a rigorous review and selection process, resulting in a set of approved observations that the MeerKAT telescope will conduct over a designated period.

The Open Time Call process is managed via SARAO's Proposal Workflow System (PAWS) [1], an information system designed to handle proposal submissions and reviews. Once proposals are approved, the planning and scheduling of these observations are carried out using the Observation Planning Tool (OPT), a tool developed by SARAO. The OPT allows astronomers to define, plan, and refine their observation strategies, ensuring that the MeerKAT telescope is used efficiently to meet the scientific objectives of each approved project.

This paper outlines the functionality, design rationale, and continuous improvements of the OPT. Key features include an integrated calibrators catalogue, the ability to simulate or "dry-run" observations, and a scheduling assistant that supports the Scheduler in optimizing observation sequences. Together, these capabilities enable SARAO to better manage valuable telescope time, improve operational planning, and ensure the delivery of high-quality, scientifically valuable data to the global astronomy community.

BACKGROUND

Before the development of the OPT the process of preparing and executing observations on the MeerKAT Radio Telescope was largely manual and fragmented. Astronomers and operators relied on submitting individual schedule blocks by hand, with supporting tasks spread across multiple disconnected systems. For example, elevation plots had to be generated through custom Jupyter notebooks (see Fig. 1), while scheduling was managed through static documents containing observation times and dates.

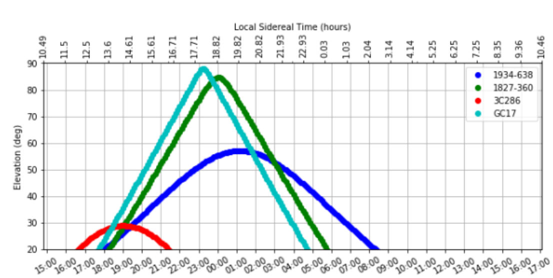

Figure 1: Elevation plot from jupyter notebook.

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Observation setup often required running separate scripts and methods for each step: for instance, `configure_obs()` was used to configure the instrument, `obs.sb.new(owner="Zanele Kukuma")` to assign ownership of a schedule block, and `obs.sb.unload()` to detach a schedule block once completed. Similarly, links to logs, calibration reports, and file handles for completed observations were scattered across different systems, making the workflow inefficient and difficult to track.

The limitations of this distributed approach motivated the development of the OPT. The goal was to consolidate all essential functions such as planning, configuring, scheduling, and logging, into a single integrated system. The OPT provides a central platform that not only streamlines observation planning but also integrates with Google Calendar, enabling easier scheduling, and improved visibility for the entire team. This unified approach improves efficiency, transparency, and accessibility, ensuring that observation planning is both scientifically robust and operationally sustainable.

SYSTEM OVERVIEW

Purpose, Workflow And Key Features

The development of the OPT was motivated by the need to streamline and centralize the preparation of MeerKAT observations. The OPT was therefore designed to consolidate these functions into a single integrated platform, accessible on the public internet to all users with a valid Proposal ID.

The OPT provides a visual environment for defining and managing observations. Its key functions include defining appropriate schedule blocks for proposals, populating potential telescope observation schedules, simulating planned observations, reporting on completion status, and notifying users of progress and outcomes. During planning, astronomers specify parameters such as telescope and correlator configurations, start and end times, and target and calibrator sources. The OPT allows users to simulate planned observations with or without a telescope setup, producing graphs and tabular outputs for validation.

Through its integration with the MeerKAT Control and Monitoring (CAM) system, OPT generates schedule blocks containing configuration data (proposal ID, owner, description, resources, timing, etc.), each uniquely identified for execution. It further enhances coordination by generating Google Calendar entries, which assist astronomers and telescope operators in maintaining awareness of planned activities. Ultimately, schedule blocks are executed by operators via the CAM system and the scheduler process [2].

Purpose, Workflow And Key Features

The OPT can be used to either plan MeerKAT observations when writing proposals, or to create observations and submit them to the observing queue when the Principal Investigator (PI) has been allocated MeerKAT observing time.

Planning:

- Simulate and plan observations ahead of MeerKAT OTC to strengthen the proposal.
- Users do not require a valid Proposal ID at this stage.
- Observations can not be submitted, but can be downloaded for future.

Submission:

- OPT is used to create and submit observations after the observation time has been awarded.
- The PI of the proposal is notified via email.
- The email contains a valid proposal ID.
- In the OPT the PI will have access to their associated proposal ID.
- OPT observations with a valid proposal ID can now be submitted to the observation queue for review.

Operational Workflow

The observation block workflow begins with the initiation of a new observation block by the Principal Investigator (PI). In its initial DRAFT state, the PI defines the target, sets the observing parameters, and refines the details. Once satisfied, the PI submits the block for review, moving it into the SUBMITTED state. The Science Operations team then reviews the block to ensure it meets scientific and technical standards. If the block is ACCEPTED, it is scheduled for execution on the MeerKAT telescope, transitioning into the SCHEDULED state. If the block is declined, the PI must revise it according to the feedback and resubmit it, returning the workflow to the submission phase. After the observation is conducted, the Science Operations team examines the archived data to assess its quality and completeness. If the observation is successful, the process reaches the COMPLETE state and concludes. However, if the observation fails, the Science Operations team clones the original block, creating a new version for rescheduling. After this cloned block is submitted, it is then accepted and scheduled for another attempt. The workflow continues in this loop until the observation is either successfully completed or ultimately deemed unsuccessful, at which point the process ends (see Fig. 2).

Technology Stack and Implementation

The OPT is deployed using a containerized architecture orchestrated with Docker, ensuring portability and ease of deployment across different environments.

The architecture of OPT follows a three-tier design:

- Frontend Layer - The user interface is built with the Angular framework and packaged within an Nginx web server container. Nginx is responsible for serving static assets (HTML, CSS, JavaScript) and handling client requests efficiently.
- Backend Layer - A Python-based RESTful API handles business logic and data processing. The API acts as an intermediary between the frontend and the database , processing incoming HTTP requests and returning structured JSON responses.
- Database Layer - ElasticSearch serves as the primary data store, enabling fast full-text search, filtering, and analytics. It is particularly suited for handling large

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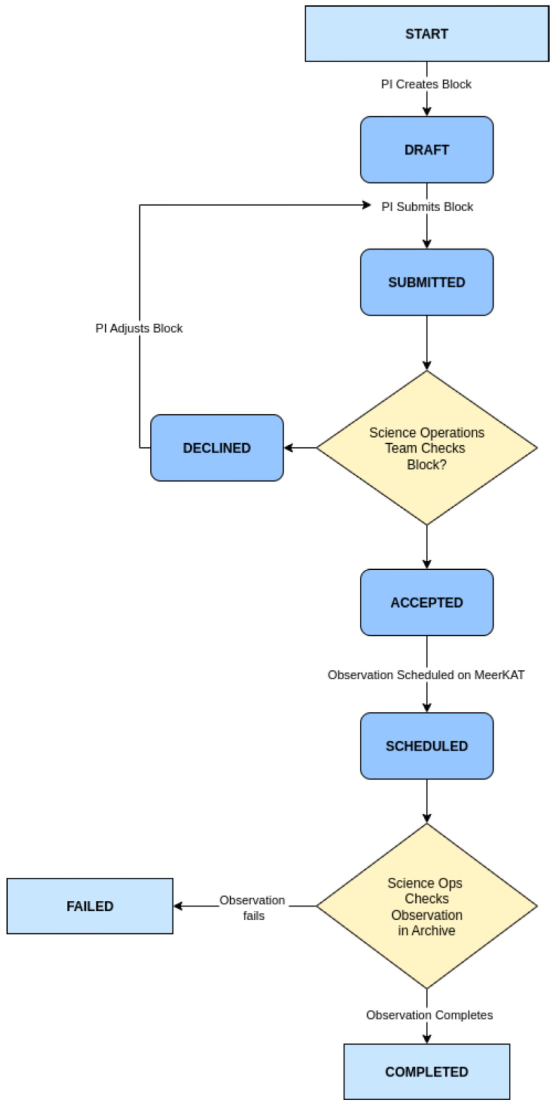

Figure 2: OPT workflow.

volumes of unstructured data with near real-time performance.

Communication between the frontend and backend occurs over HTTP, while the backend interacts directly with ElasticSearch through its native API. All services are encapsulated in separate Docker containers, enabling isolated environments.

RESULTS AND IMPACT

Since its inception in 2018, the OPT has processed over 11500 observations to date and saved countless hours of astronomer time through the use of its Web User Interface (UI). Its ease of use in planning and submitting observations has been noted by the MeerKAT user base over the years.

The tool has also improved the operational conditions of SARAO astronomers that assist in maintaining the schedule of the telescope through the various functions that are available.

CONCLUSION

The OPT was developed to address the fragmented and manual processes that previously governed the preparation of MeerKAT observations. By centralizing the functionalities such as schedule block creation, elevation plotting, configuration management, and integration with Google calendar, the OPT provides astronomers and operators with a streamlined, transparent, and accessible environment for planning and executing observations. This has not only reduced complexity in operations but also improved coordination between Principal Investigators, the science operations team, and telescope operators. Looking ahead, the OPT will continue to evolve in response to user feedback and the operational demands of MeerKAT. Its design ensures that new features can be easily incorporated, paving the way for integration with the SKA.

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